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Evolution of Minimum Mortality Temperature in Stockholm, Sweden, 1901-2009

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Running head: Minimum mortality temperature in Sweden, 1901-2009

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Abstract

Background: The mortality impacts of hot and cold temperatures have been thoroughly documented, with most locations reporting a U-shaped relationship with a minimum mortality temperature (MMT) at which mortality is lowest. How MMT may have evolved over past decades as global mean surface temperature increased has not been thoroughly explored.

Objective: We used observations of daily mean temperatures to investigate whether MMT changed in Stockholm, Sweden, from the beginning of the 20th century until 2009.

Methods: Daily mortality and temperature data for the period 1901–2009 in Stockholm, Sweden were used to model the temperature-mortality relationship. We estimated MMT using distributed lag non-linear Poisson regression models considering lags up to 21 days of daily mean temperature as the exposure variable. To avoid large influences on the MMT from intra and inter annual climatic variability, we estimated MMT based on 30-year periods. Further, we investigated whether there were trends in the absolute value of the MMT and the relative value of the MMT (the corresponding percentile of the same day temperature distribution) over the study period.

Results: Our findings suggest that both the absolute MMT and the relative MMT increased in Stockholm, Sweden over the course of the last century.

Conclusions: The increase in MMT over the course of the last century suggests autonomous adaptation within the context of the large epidemiological, demographical and societal changes that occurred. Whether the rate of increase will be sustained with climate change is an open question.

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1. Introduction

Extreme ambient temperatures, be it hot or cold, are known to cause negative effects on human health (Anderson and Bell 2009; Kovats and Hajat 2008). The temperature-mortality relationship is often described as a J or U-shaped curve, with a temperature at which mortality is at a minimum or the Minimum Mortality Temperature (MMT) (Baccini et al. 2008; Curriero FC 2002; Guo et al. 2014; Leone et al. 2013; McMichael et al. 2008; Medina-Ramon and Schwartz 2007). This minimum temperature varies greatly across countries and regions ranging from a daily mean temperature of 10-12°C in Scandinavian countries (Nafstad et al. 2001; Näyhä 2007) to 27°C in Miami (Curriero FC 2002).

If the shape of the temperature distribution remains the same in a warmer climate, albeit with a higher mean temperature, and if MMT is a stationary measure over time, then one would anticipate, all other factors being equal, that as the proportions of temperatures above and below the MMT threshold shift, that cold-related mortality would decrease and heat-related mortality would increase. Evidence shows that temperature distributions are shifting to more days with warmer and fewer days with colder temperatures (Field 2012). Mean daily temperatures increased over the 20th century in Stockholm, Sweden, (SMHI) with temperatures projected to further increase (Nikulin et al. 2011).

Adaptation could offset some of the mortality from higher temperatures by shifting the MMT to the right. To support this, reduction of short-term mortality to regional hot temperatures extremes over time has been observed in Stockholm, Sweden (Åström et al. 2013b). A few other studies document the extent to which adaptation and acclimatization occurred over the 20th century (Carson et al. 2006; Ekamper et al. 2009;Petkova et al. 2014). As a consequence of increasing

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temperatures there is speculation that climate change might itself be a factor for acclimatization both on an individual level (physical acclimatization and use of air conditioners), as well as a societal level (urbanization) (Parry 2007). There is also speculation that milder temperatures will bring excess winter mortality down (McMichael and Lindgren 2011), although the evidence base is limited.

MMT could be affected by changing demography, particularly an increased proportion of elderly in the population. The expected increase in the number of elderly and other potentially vulnerable groups, in absolute numbers and as a proportion of the population, could make the impact of temperature extremes on human health more severe (Sierra et al. 2009), because the elderly and chronically ill are more sensitive to temperature extremes (Anderson and Bell 2009; Basu 2009; Oudin Åström et al. 2011).

The aim of the present study was to investigate whether MMT changed in Stockholm, Sweden from the beginning of the 20th century to the present. To our knowledge, this is the first study of the evolution of MMT to use daily mortality and temperature data spanning more than a century, giving more power to test for trends.

2. Materials and Methods

We collected daily mortality and temperature data for the period 1901 to 2009 for present day Stockholm County, Sweden. The mortality data were deaths from all causes (Släktforskarförbund 2010). The meteorological data were daily mean temperatures provided by the Swedish Meteorological and Hydrological Institute (SMHI), (SMHI 2013). Temperature data have been recorded in Stockholm at almost exactly the same location since 1756.

2.1 Statistical Methods

The evolution of MMT over time was modelled using a time series approach where the daily counts of mortality were assumed to follow an overdispersed Poisson distribution. The temperature-mortality relationships were modelled using a distributed lag non-linear model (DLNM) with a lagged period of 21 days to account for the immediate effects of heat as well as short term mortality displacement. 21 days should be sufficient to capture the more delayed effects of cold (Gasparrini et al 2014).

To avoid large influences from intra and inter annual climatic variability as manifested by an unusually large number of temperature extremes in some decades, we estimated MMT for 30-year periods containing daily observations for mortality and temperature. The smoothed evolution of MMT, explaining broad patterns of change, was examined by stepwise repeating the model across the century including 30 years of data in each model changing the time period of study by 1 year at a time. The first data point created for calculation of MMT thus corresponds to observations for the period 1901-1930, the second for the period 1902-1931 and so forth until the last data point that corresponds to the period 1980-2009. The model was run 80 times and for each period the MMT was extracted.

MMTs for Stockholm were derived using the model for each of the different periods investigated:

$Y_t \sim \text{Poisson}(\mu_t)$

$$\log(\mu t) = \alpha + \beta Tti + weekdayt + holidayt + NS(trend, df=8 \text{ per year}) \qquad [1]$$

Where Y_t is the number of deaths occurring in Stockholm County on day t, α represents the intercept, βT_{ti} is a vector of i coefficients representing the non-linear and lagged effects of mean temperature on day *t*, modeled as a quadratic B-spline with two equally spaced knots for temperature, and a natural cubic spline with three equally spaced knots (log scale) for the 21-day lag period, respectively. Weekday is a categorical variable for day of week and holiday is a binary variable indicating public Swedish holidays. NS(trend) is a natural cubic spline with 8 degrees of freedom per year to take into account variability in mortality due to seasonality and longer term time trends.

Sensitivity analyses were carried out using 10 degrees of freedom for the time trend.

In addition, for each 30-year period we estimated the relative value of the MMT, defined as the percentile of the same day (lag0) temperature distribution corresponding to the absolute value of the MMT, to see if changes in the MMT over time are accompanied by changes in its location within the overall temperature distribution.

The smoothed evolution of MMT over time did not have more than three independent time periods of observation at the same time. To be able to draw valid inference regarding the evolution of MMT, we used data from non-overlapping, thus independent, time periods of 10 and 20 years of data. The 10-year periods investigated were 1901-1909, 1910-1919, etc. up until 2000-2009. The 20-year periods investigated were 1910-1929, 1930-1949, 1950-1969, 1970-1989 and 1990-2009. Using the same model as above we derived MMTs for the independent time periods. We then investigated if a trend over time could be detected using linear regression models with either the absolute MMT or the relative MMT as the dependent variable, and time as the independent variable.

SAS version 9.2 software was used to create datasets and variables. R version 2.13.1 package DLNM was used for statistical models and creation of outputs.

3. Results

We observed an apparent trend over time for both the absolute MMT and the relative MMT (Figure 1). During the period before the 1950 MMT were found at lower temperatures and were much more variable as compared to the latter part of the study period.

Throughout the last century, MMTs ranged from 10.3°C to 20.0°C (median = 17.4°C). Relative MMTs ranged from the 64th to 95th percentile of the lag0 temperature distribution (median = 90th percentile).

Similar results were found in the sensitivity analyses using 10 degrees of freedom for the time trends (results not shown).

Estimates of MMT for non-overlapping 10- or 20-year periods were more variable (Figure 2). We estimated an increasing trend for the absolute value of MMT over time (βtrend 10 years = 0.8; 95% CI: 0.2, 1.4 and βtrend 20 years = 2.4; 95% CI: –0.0, 4.8). Relative MMT as a percentile of the overall distribution also increased over time when estimated for independent 10-year (βtrend 10 years = 2.2; 95% CI: 0.2, 4.3) and 20-year periods (βtrend 20 years = 7.1; 95% CI: –3.3, 17.5).

4. Discussion

We report an increasing trend over time in MMT in Stockholm, Sweden. Over the course of the last century large changes occurred in Swedish society, yielding large benefits to public health. Housing standards improved significantly after the 1950s with the introduction of central heating and sanitary conditions were improved. The epidemiological transition changed mortality patterns and delayed mortality to older ages (Omran 1971), resulting in increasing life expectancy at birth and a larger proportion of the population being elderly. For men and women, respectively, life expectancy at birth increased from around 53 and 56 years during the early 1900s to around 79 and 83 in 2009 (Statistics Sweden 2015). The percentage of deaths taking place in the age category above 65 years population increased from approximately 30% during the1900s and the 1910s to above 75% from the 1980s and onwards. The uncertain employment conditions especially during the early 1920s and early 1930s were followed by a period with almost full employment during the 1950s and 1960s, leading to more economic security for families and individuals (Magnusson 2000). GDP per capita increased substantially over the study period (Statistics Sweden 2015).

Mean temperatures in Stockholm increased from 6.0ºC during 1900-1929 to 7.4ºC during 1980-2009 (SMHI 2013). We observe an increasing trend in MMT over the last century in Stockholm, Sweden. Our results suggest the MMT could continue to increase with increasing temperatures; however, changes in personal and social determinants of health may alter this trend in the future. Our results for the end of the study period are similar to a recent study where MMT in Stockholm, Sweden was reported at the 93rd percentile for the period 1990-2002 (Gasparrini et al 2015).

Our results contradict a previous study of the MMT and its evolution over time, where Miron et al (2008) concluded that the maximum temperature of minimum mortality decreased significantly towards lower temperatures in Toledo, Spain during the years 1975-2003. They attributed this fall to an increasing effect of heat on mortality and argued that it was due to an increasing percentage of the population being elderly, thus, on a population level, more susceptible to mortality during heat waves. Our results are in agreement with a recently published study of the evolution of MMT over time, where Todd and Valeron (2015) found

MMT to have increased in France during the years 1968-2009. The authors suggested partial adaptation to increasing temperatures as one potential factor explaining their finding.

Mortality during the winter months is mostly due to cardiovascular disease (e.g. myocardial infarction) and respiratory disease (Ebi and Mills 2013). The balance between winter and summer deaths may be altered by a changing climate, however one review concluded that winter mortality rates are unlikely to decrease significantly due to warming (Ebi and Mills 2013). Staddon et al (2014) conclude that no evidence exists that excess winter deaths in England and Wales will go down as a result of warmer winters. A previous study in Stockholm reported that high levels of winter mortality reduced the estimated effect of high temperatures on mortality during the following summer (Rocklöv et al. 2009).Similar results were reported in Rome, Italy, a region with warmer climate than Stockholm (Stafoggia et al. 2009). High levels of winter mortality will deplete the pool of susceptible individuals, likely negatively affecting the MMT because more people will die from lower hot temperatures or at less extreme heat. Recently Hajat et al (2014) came to a similar conclusion when projecting future temperature related mortality in the UK, where the burdens of cold temperatures were higher than the burden of hot temperatures for all periods, with the elderly most at risk.

The full range of the temperature-mortality relationship must be considered when evaluating the health impacts of any change in the MMT. The slopes of cold- and heat-related mortality differ, and at the extremes of the temperature range, heat generally has a much steeper slope than cold.. And these slopes will differ by region (Rocklöv and Ebi 2012). The estimates of MMT derived in our study depended on the number of years included in the study period, therefore the derived MMT for a specific region might change with increased data availability. Furthermore our derived values would likely change to some extent if the non-linear temperature-mortality relationship was modelled differently or the degrees of freedom were changed. We did not explore whether there have been any changes in the temperature-mortality relationship, a relationship likely to have changed over time as well. Therefore, the results should be interpreted made with some caution because the impact of temperature on health differs with the slopes of the temperature-mortality relationship. A steeper slope for heat or cold from the MMT would have more severe impacts on health compared with a shallower slope, even though MMT is identical.

If the absolute value of the MMT is fixed and all other factors are held constant, climate change (warming temperatures) would shift the relative MMT to a lower percentile of the temperature distribution. Similarly, if the relative MMT were fixed at a specific percentile of any current or future temperature distribution, climate warming would tend to increase the absolute value of the MMT to a higher temperature. Our trend estimates based on independent 10-year periods suggest that assuming a constant value for the relative MMT (i.e., that MMT is fixed at a specific percentile of the temperature distribution, regardless of changes in the distribution over time) may not be appropriate for projecting future impacts because the relative MMT may not be a valid proxy for the absolute MMT in the future. However this was not supported to the same extent using independent 20-year periods, suggesting more research is needed.

Extreme high temperatures are increasing in frequency and intensity, which is increasing heat-related mortality (Smith et al 2014), however it is reasonable to expect that people and societies can, over time, adapt to gradual increases in average temperatures, up to some limit. Our study makes use of historical data, making it difficult to separate adaptation due to co-benefits from the large medical, epidemiological and societal changes occurring in Sweden across the last century from planned actions to counter the effect of gradually increasing temperatures. For Stockholm, Sweden, the association between extreme hot temperatures and short-term mortality decreased over the time period 1901-2009 (Åström et al. 2013b) A recent study in the United States reported that, over time, heat-related mortality rates for people age 75 years and older are declining toward rates for the 65-74 year age group, suggesting adaptation to elevated temperatures (Bobb et al. 2014).Public awareness of the negative impacts on public health caused by elevated temperatures is, in general, low in Sweden. During the period 1980-2009 limited adaptation occurred to the number of temperature extremes occurring on a yearly basis (Åström et al. 2013a). Furthermore, in a colder climate like Sweden's, we suspect the increased capacity of the society to cope with cold exposures through more widespread and efficient indoor heating may have contributed to lowering the MMT threshold.

More research is needed on the evolution of MMT over time because it may not be appropriate to assume an increasing trend in absolute MMT, or that MMT is fixed at a specific percentile of the temperature distribution, when projecting future temperature-related mortality. Better understanding of the evolution of MMT could inform projections of the likely future burdens of heat- and cold-related mortality over coming decades.5. Conclusion

Our finding that MMT has increased over time in Stockholm, Sweden could inform projections of future impacts of climate change on public health, addressing concerns that projections may have overestimated risks by not considering adaptation.   In addition to including changes in MMT, projections also should consider other drivers of temperature-related mortality, such as demographic, epidemiological, societal, and behavioural changes in human populations.

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Figure Legends

Figure 1. Estimates of Minimum Mortality Temperature (MMT) during 1901–2009 in Stockholm, Sweden. Filled circles indicate the absolute value of the estimated MMT (ºC), open triangles indicate the corresponding estimate of the MMT as a percentage of the temperature distribution. Estimates were derived using distributed lag non-linear models of 30-year moving averages with a 21-day lag, adjusted for weekdays, holidays, and smoothed time trends (8 df per year). The smoothed evolution of MMT was examined by stepwise repeating the model across the century including 30 years of data in each model changing the time period of study by 1 year at a time. The first data point created for calculation of MMT thus corresponds to observations for the period 1901-1930, which was centered around the year 1915, the second for the period 1902-1931 (centered around the year 1916) and so forth until the last data point that corresponds to the period 1980-2009.

Figure 2. Independently estimated Minimum Mortality Temperatures (MMT) during 1901–2009 in Stockholm, Sweden. Filled circles indicate the absolute value of the estimated MMT (ºC), open triangles indicate the corresponding estimate of the MMT as a percentage of the temperature distribution. Estimates were derived using distributed lag non-linear models of independent 10 and 20-year periods with a 21-day lag, adjusted for weekdays, holidays, and smoothed time trends (8 df per year

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Figure 1.

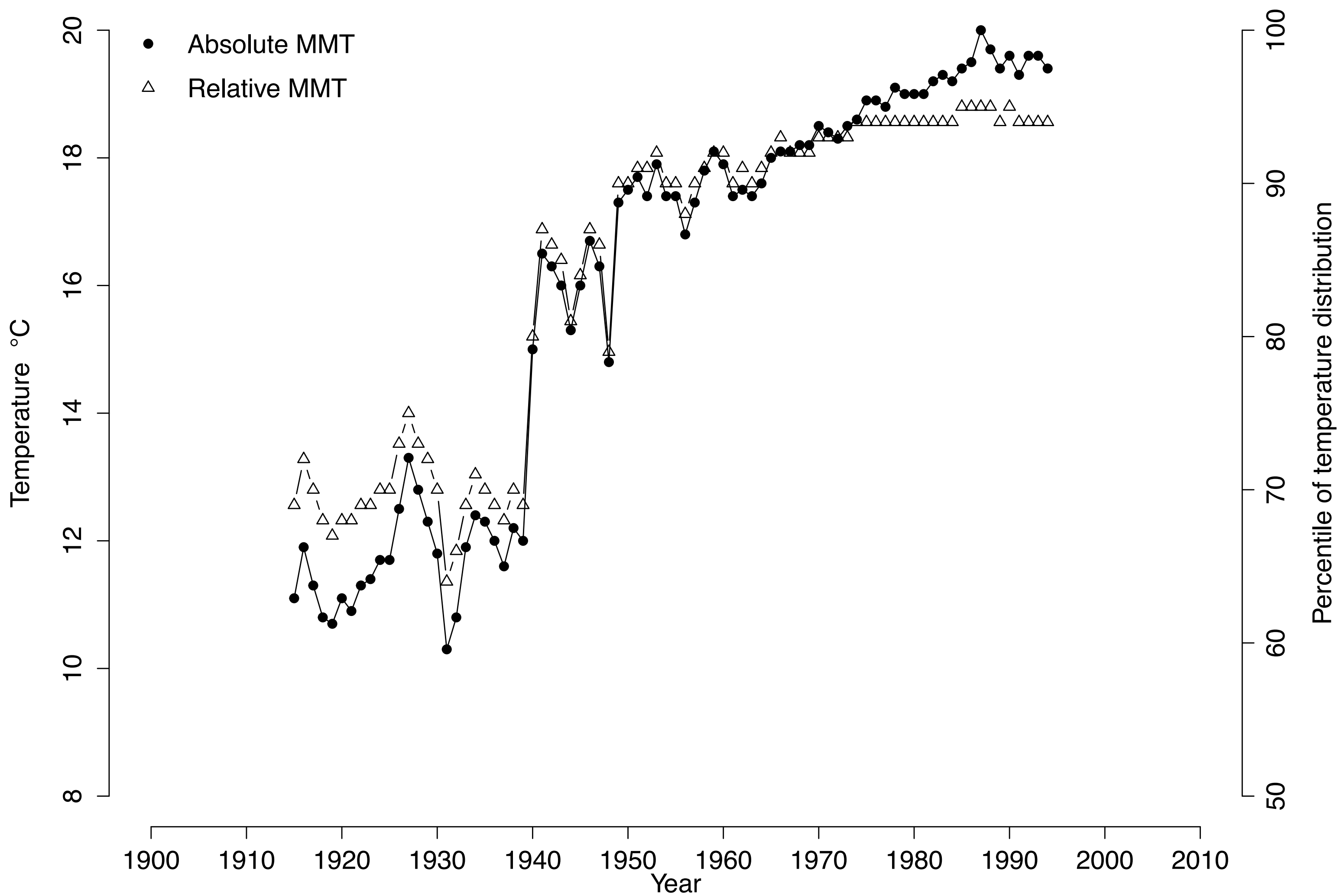

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Figure 2.